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MINISTRY OF TECHNOLOGY

EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT

TECHNICAL REPORT No. 9

Recent Investigations on Burning to Detonation (U)

A.L. Lovecy

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3 Recent Investigations on Burning to Detonation (U)

by

4 A.L. Lovecy

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SUMMARY

With a view to a more rigorous application of scientific principles to the problem of premature detonation of RDX/TNT fillings in shell, recent experiments on ignition and propagation in secondary explosives are briefly described. These lead to certain conclusions which need to be taken into account in formulating an acceptable mechanism for shell prematures. As a result, it seems that ignition of the filling is an insufficient cause for detonation except in circumstances where pressures substantially in excess of the yield-strength of the shell wall can also be generated, for instance by impulsive loading as in an impact. Some indications of the scope for future experimental studies are mentioned briefly.

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1. INTRODUCTION

Experimental work which has been reported in a series of ERDE Technical Memoranda during the past four years, under the general title "Electrothermal Ignition and Propagation in Solid Explosives", has led to a clearer understanding of the connection between these processes and the initiation of detonation.

The following paper deals with aspects of the work which are thought to be applicable to the recognition and eventual control of the causes of shell prematures. A great deal of attention has already been given to these incidents because of their exceptional importance. It will be shown, however, that there is still scope for a more exact use of general principles on this subject. The nature of the scientific problem, in bare skeletal form, is given first.

It is a matter of fact that main fillings of RDX/TNT in shell have prematurely exploded on numerous occasions. Three, at least, began from non-explosive stimuli (i.e. not fuze-initiated) and among these one at least was a high order detonation.

These experiences prove that a mechanism for producing high order detonation in RDX/TNT from non-explosive stimulation does actually operate in the given circumstances.

This is equivalent to stating that a rigorous description of the mechanism(s) from start to finish can be formulated by correct use of known or ascertainable facts about the behaviour of the component articles. Although such a formulation has not yet been completed, and perhaps may never be entirely within our grasp, the nearer we approximate to it, the better for safe gunnery.

2. BASIC CONCEPTS

For any proposed mechanism to merit credence, no unproven properties or phenomena can be included. Until all the requisite pieces of information are substantiated, a hypothesis founded on them must be regarded as speculative. Progress does, of course, depend on speculation, including the use of conjectural phenomena or properties. What is particularly useful, then, is to state the conjectures explicitly and in a form such that validation can be attempted.

For this purpose, it is especially necessary to differentiate between establishing the features of the gun, shell, etc., and those of RDX/TNT itself. To ignore this, in favour of a direct study of the long-odds interactions between the two participants, is a sure road to the unprofitable use of resources.

/Granted .....

Granted a satisfactory mechanism to account for the full detonations, the occurrence of lower-order events can be explained as an interruption of the mechanism during development. For this to be consistent, the mechanism has to include an intermediate regime which responds in some way to circumstances and is able to persist, perhaps unsteadily, but neither progressing inevitably to detonation nor decaying rapidly away.

Initiation of detonation by a non-reactive (i.e. purely physical) shock stimulus, a process which has been studied extensively in gap-tests, does not satisfy these requirements. In the most marginal cases, application of a nominally plane or one-dimensional shock at threshold strength leads straight to detonation within microseconds. If the entering shock is too weak or too transient to cause detonation, however, the reaction it produces is not self-supporting and decays away.

The characteristic feature of shock-initiation is the presence of a certain shock-strength before reaction commences. The only known alternative mode of initiation of detonation is the converse process; that is, a process in which ignition takes place first, without a shock of threshold strength until a later stage. This is the process of thermal initiation of detonation, or burning to detonation. Both terms signify that self-supporting decomposition (ignition) of the explosive is the definitive step, without restriction as to the particular heat-sources which may be responsible for the ignition.

In the various discussions which have previously taken place, the probability has clearly been accepted that actual prematures do come about through burning to detonation. The preceding paragraphs, summarising the logical basis for the same conclusion, also urge the need for an explicit account of the process. This important requirement seems to have been neglected hitherto: attention has been directed to the other important and more conspicuous question of how the ignition arises in the first place, rather than asking why detonation is its result. As we shall see, the latter is also a valid question.

Since we are concerned with the elimination of prematures we cannot afford to ignore any part of the causative sequence. At a given level of probability of ignition, the risk of actual detonation will generally be very much smaller, because it depends also on the probability of growth. For this reason, the following brief results of recent investigations on the process of burning to detonation are directly relevant to a proper understanding of this problem and how best to deal with it.

By learning more about the conditions of growth, we shall be in a better position to assess the effects associated with a given design feature or discrepancy in the articles concerned, and to examine potential remedies objectively. With this in view, it is suggested that techniques used in the experiments described could probably be adapted to assist further work specifically directed to prematures.

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3. EXPERIMENTAL GROUNDWORK

3.1 Primary and Secondary Explosives

When a few milligrammes of explosive is placed in an open spoon of thin metal and touched with a gas-flame, two fairly distinct types of behaviour may result. Either there is an explosion with a characteristic bang or sharp crack, or else a less violent combustion with a puff or spurts of flame. With larger amounts laid down as a narrow, linear trail the difference can often be appreciated as a matter of speed as well as violence.

Behaviour of the first kind, i.e. exploding instantaneously on ignition, is typical of primary explosives as a class. Because of their ready response to the non-explosive stimuli by which any explosive system has to be triggered into action, this is the class which furnishes the initial or primary component for most explosive systems.

Explosives with the other kind of behaviour, the class of secondary explosives, are useful in the main charges of weapons since these need only respond to the relatively powerful explosive output from the primary stage. Their lack of ability to detonate immediately on simple ignition therefore counts as an advantage.

3.2 Internal Ignition

When localised decomposition is started in a secondary explosive by quickly raising the temperature at some point, layers near the source of heat are the first affected, and propagation depends on passing enough heat to the neighbouring layers in turn. To set up a self-supporting reaction, indispensable for propagation, the source must supply at least a certain minimum of heat during an adequate period of time. This can be done very efficiently by passing a current through tiny carbon fibres randomly mixed with the powdered explosive. The method was devised for the purpose of these investigations and patent protection is in hand. Stored energy of 5 mJ at 50V is quite adequate to ignite RDX, for instance, when consolidated in a steel tube of a few millimetres bore. Higher voltages were generally used in the experimental work, however, since the chief interest was in the subsequent processes.

This is a convenient method of producing hot-spots or ignition-nuclei in the charge, essentially identical with the hot-spots which could originate from grit particles (see 5.6) or from adiabatically-compressed gas inclusions, in the practical use of explosives.

3.3 Stress Effects of Ignition

In Fig. 1, (a) and (b) represent two typical assemblies used in these investigations. In (a), a sleeve made from mild steel rod, e.g. 12.5 mm diameter, 10 mm long, with an axial bore 1.6, 2.4, or 3.175 mm, is fastened by adhesive to a base of the same stock. A layer of paper is interposed for

/electrical .....

electrical insulation, through which an electrode of 22 SWG wire projects 4 mm axially from the base into the bore. Talc, consolidated by pressing with a hollow drift, forms a gas-tight seal at the lower end of the annular space. The assembly (b), following the same principles, is made from 6.35 mm bright steel, typically 15 mm long. In this design the main bore terminates 2 mm (at axis) from one end of the sleeve and the electrode passes through a narrower aperture, clearance 0.1 mm, to give a stronger seal.

With an assembly of type (a), a layer of the explosive/fibre mixture, 0.5 mm, was pressed with a 3 mm column of PETN above it. On firing by passing current between the axial-electrode and the bore wall, the column of explosive was ejected. In experiments designed for recovery of the residue it was found that only a very minor amount had been consumed: 2 mg was missing from a charge originally 30 mg, for instance. When, however, the column length was increased by only 1 mm, the whole charge exploded. Similar results were obtained with RDX.

The quenching of the reaction in these experiments corresponds with the following mechanism. Gaseous products formed on ignition exert sufficient pressure at the closed end to propel the whole column along the bore. Simultaneously the expansion of the reaction-products lowers their temperature so much (see section 4) that insufficient heat is transferred to the virgin material to keep the reaction going at the original rate; decay follows quickly.

With a greater mass initially, a higher pressure has to be reached before similar motion can occur; a larger stock of hot products is involved and the mass rate of reaction is also raised. The consequent surplus of heat of reaction over the kinetic expenditure of energy in displacement is thus sufficient to maintain propagation.

3.4 Propagation in Long Columns

By using columns of explosive 20 mm long or more, the pressure needed to produce a given motion is correspondingly increased and a higher mass rate of reaction is reached before displacement. Nevertheless, experiments made with type (a) assemblies in these conditions did not reach full detonation. In all cases the pressures attained were sufficient to expand the bore; and by dissipating energy in this way some limitation was placed on self-heating and acceleration of the chemical reaction. Detailed explanation is unnecessary as the immediate concern is with observed results.

A steel disc was attached to the open end of the sleeve but electrically insulated from it by disc of paper, both having perforation to correspond with the bore; the arrival of the ionised flame front at the open end of the column (the bore having been filled completely with PETN above the igniting layer) gave sufficient electrical conductivity across the thin peripheral gap to actuate a thyratron and so serve as a stop signal for an electronic chronometer.

/Action .....

Action time from the closing of the firing switch to the operation of the ionisation-gap was thus recorded, typical results being 19, 20 μs for 20 mm length and 22, 23 μs for 30 mm length, in both cases using PETN in very thick-walled sleeves (2.38 mm bore, 18 mm o.d.).

Usually, the bore was enlarged to 3.17 mm or just above, and sleeves longer than 25 mm cracked lengthwise at the outside. The cracks extended only part way toward the bore; but generally they spread and became wider during subsequent weeks of storage, because of the residual stresses associated with high rates of strain and relaxation.

A simpler ionisation-gap for timing was made by resting a steel rod, 6.35 mm dia by 50 mm long, in a vertical position on the open end of the charge, with a perforated disc of varnished fabric insulation interposed. The massive rod (12.5 g) also provided greatly increased impedance to displacement of the charge. Lengths of bore 30 mm gave 20, 20 μs, and lengths 40 mm gave 23, 22, 23 μs.

An electrode of 22 SWG wire was imbedded to a depth of 10 mm in a PETN column 40 mm long, by using a hollow drift for the final stages of the filling. This enabled the stop signal to be taken at the axis instead of the periphery of the charge, and within the column instead of at the open end. The action time for 30 mm thus recorded was 20 μs, the same as in the restraint rod experiments and 2 to 3 μs less than the peripheral gap had given. The differences are small enough to confirm that the three varieties of detector are all triggered by the reaction-front as intended.

Taken at face value these measurements indicate mean propagation speeds from 1 mm/μs at the least and up to 2 mm/μs at most. There is clear evidence of acceleration, but even in the longest sleeves the final velocity seems to reach about 3 to 5 mm/μs rather than the full detonation value upwards of 7 mm/μs.

The damage to the sleeves confirms that the reaction approximates to but does not equal full detonation. As a specific instance, a 40 mm long sleeve 18 mm o.d. and 1.58 mm bore was fired with restraint rod timing, 22 μs. The expanded bore was less than 2.38 mm dia except for the slight bell-mouth at the exit, due to gas wash, which is usual in these experiments. On the other hand, when 20 mm long sleeves of the same o.d. and bore were fired by contact of an electric detonator, the bore enlarged to almost 3.175 mm; less than 4 μs of the action time was attributable to the sleeve.

3.5 Displacement Dynamics

Assemblies of the type (b) of Fig. 1 were used in simple experiments to measure the mechanical data relating to the effects of ignition and propagation. The amount of PETN used was arranged to leave a certain length of the bore empty; the column, being fairly short, was propelled along the bore by

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the pressure developed on ignition at the closed end but the conditions did not allow quenching as in section 3.3. On the end of the column was a thin metal disc, enabling the time of arrival at a given point to be recorded by contact with a suitable electrode connected to the timing-circuit.

For example, in 1.58 mm bore, with only 2 mg of PETN/carbon fibre on to which 6 mg talc and a 15 mg disc of brass were pressed, the recorded action-time for the minimum detectable displacement was 5 to 6 μs. The detector probe for these experimental measurements was a pointed steel rod of 1 mm dia placed vertically in the sleeve with a loose liner of thin paper between. The point rested on a disc of thin paper (44 μ) which had already been pierced by pressing on the rod and releasing it so that contact with the brass disc below just failed.

Particularly interesting results were obtained when a steel witness-plate about 15 mm square and 2 mm thick was fastened to the open end of the sleeve with insulating cement, and connected to record the total action time from application of firing current up to the arrival of the brass disc against the plate, originally 4 mm apart. With only 40 mg of PETN in the sleeve, 2.38 mm bore, the action time recorded was 18 μs and a clear hole 3.3 mm diameter was pierced through the plate.

Calculating as though the acceleration had been uniform, the mean velocity and acceleration found are 222 m/s and 24.7 megametres/s^2. The acceleration multiplied by the original mass of the charge plus disc, 73 mg in all, shows the mean value of the force acting is 1800 N which, on the 4.4 mm^2 of bore area concerned, amounts to 4×10^8 N/m^2 or 4 kilobars. All these results of calculation are under-estimates, of course, since no allowance has been made for ignition-delay and the like. These are typical of the figures obtained from a large number of experiments of this kind, which have led to a better insight into the nature and mechanism of the initiation process generally.

For the present purpose, the special interest of these results arises from the sharp contrast between the limit reached in velocity and pressure with far larger charges fired under far stronger restraint (section 3.4) and the evident speed and violence with which the small residual charge reacts after impact with the witness plate.

The reason for this great speed and violence is quite a simple one in terms of mechanics. The residual charge (and disc) impelled by force F during a time t acquires momentum equal to the impulse Ft. On impact it is brought to rest in a shorter time, t/n say, and therefore is subjected to a decelerating force n times as large as F. Accordingly a compression stress n times as great as the reaction-zone pressure is transmitted back from the impacted end towards the reaction-zone and must arrive there within a micro-second or so. Thereupon the process of expansion of reaction-products, until then driving the charge forward, is halted and the local pressure raised to correspond. Reaction-energy therefore raises the local temperature and rate of propagation in the charge to a much higher level than was formerly possible

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whilst the charge was in motion with the reaction products expanding to the rear. In other words, the reaction becomes self-accelerating again as a consequence of the sudden arrest (or decrease) of movement by the impact.

A precisely similar course of events is brought about if the moving charge is impacted upon another column of explosive instead of a steel plate. In this case the result is a high order detonation of the secondary charge serving as the anvil. Fig. 2(a) shows a "secondary explosive detonator" embodying this principle, and Fig. 2(b) shows the result of firing it.

4. CONSIDERATIONS RELEVANT TO PREMATURES

The experimental results obtained with long columns of PETN, strongly confined in steel and reliably ignited, amount to conclusive proof that in the case of a distinctly less energetic and less sensitive composition such as RDX/TNT simple ignition does not provide an adequate explanation of the occurrence of high order detonations in shell.

On the other hand, however, direct initiation by shock is equally unacceptable to explain the many other incidents in which the final results were less severe than high order detonation.

Considering the available evidence as a whole, the most probable mechanism does seem to be of the general character which is described for PETN in section 3.5. That is to say, there is a finite probability of local ignition in a proportion of shell. Then in some of these instances, there is an additional contributory factor of the nature of high pressure suddenly imposed on the reaction zone by mechanical means, perhaps by impulsive compression. Cases where ignition occurs but the second factor does not operate can result either in low-order events, or in quenching.

For the sake of clear understanding, the cooling of reaction-products by expansion must now be formulated explicitly. The products consist essentially of a mixture of gases (CO, CO_2, N_2, H_2, H_2O) which will expand adiabatically, so that pv^{γ} is constant. A reasonable estimate for the value of the specific heat ratio, γ, is 1.35. When a compressed volume v_c expands to the new volume v_x, the relationship of the final temperature Tx to the original temperature Tc is given by

$$Tx/Tc = (v_c/v_x)^{\gamma-1} = (v_x/v_c)^{0.35}$$

By way of illustration, following are three representative values of v_c/v_x and the corresponding Tx/Tc ratios; actual values of Tx for each of two typical Tc levels are shown below them.

v_c/v_x	1/10		1/100		1/200	
Tx/Tc	0.45		0.2		0.156	
Tc, °K	4000	3000	4000	3000	4000	3000
Tx, °K	1800	1350	800	600	624	468

/It is .....

It is to be noted that the fall in temperature, therefore also in reaction-rate, is greatest at the beginning of expansion - and this is when the pressure is highest and displacement most rapid. At the earliest stage, and especially when the charge is of large dimensions, displacement due to compressibility alone will be quite significant and very rapid. Hence the actual duration of extreme temperature is certain to be very short in the compressible explosives we are concerned with.

We must appreciate, too, that the pressure attainable in the notional adiabatic decomposition of a small element is so great that upwards of half a kilobar will be exerted even after one hundredfold expansion from the initial volume. Clearly, unless restraining forces of a higher order than this are available, the temperature cannot be held more than two or three hundred degrees above the ignition-point. Steel having a tensile yield-strength of a few kilobars will act as a pressure-relief system for the growing hot-spot nearby, and thus a mechanism for continuation of burning not leading to detonation is in operation. This agrees with the observed plastic deformation of steel sleeves (section 3.4) and the pressures estimated by dynamic calculations (section 3.5).

These are fundamental considerations affecting any burning-to-detonation mechanism; despite the disparities in scale, etc., the experimental facts have direct implications for shell prematures. Limitations shown to apply in the case of PETN will be no less valid for RDX dust or grains segregated from an RDX/TNT filling; in addition, the mixture as such is still less likely to respond, both in ignition and in growth.

To arrive at such conclusions may be unexpected, even disappointing, a distraction from the main issue. This arises simply from the fact that it is unusual to seek or offer mechanistic explanations for explosives behaving safely when projected, or in rough handling, etc. The custom is to accept safety and correct functioning without much question of understanding; far more effort is put in where things go wrong! Clearly this is not a good custom, scientifically, and it is very desirable to have a proper knowledge of the reasons for normal and safe behaviour, as a basis for examining actual and potential abnormalities. The present paper attempts to serve that purpose.

Manifestly a good deal more must be added, but in principle a useful framework has taken shape, and it is convenient to sum up the indications in a few brief statements:-

(i) Ignition of secondary explosives does not cause detonation directly, because the thermodynamic properties of the reaction-products are more suited to disposing of energy dynamically (in flow and expansion) than thermally (in heat transfer and activation processes). Displacement competes against propagation.

/(ii) .....

(ii) This is the chief reason why in most circumstances secondary explosives are so much less sensitive, although more energetic, than primary explosives.

(iii) Burning to detonation takes place in conditions where the dynamic processes are suppressed by the particular restraints brought into effect, and the thermal action therefore increases.

(iv) Static yield strengths of steels are generally inadequate to ensure, per se, burning to detonation in PETN, RDX, RDX/TNT.

(v) Impulsive pressures which can be generated by impact provide one means whereby burning already in progress may accelerate to detonation.

Various possibilities come to mind as regards a source of impulsive pressure; some of the more obvious are:-

(a) sideslap of the shell forepart in a worn gun,

(b) shock transmitted through the filling when driven forward by ignition near the base and striking the head of the shell,

and (c) impact due to relative motion of parts of a cracked charge.

No useful purpose would be served by further speculation here.

5. SUPPLEMENTARY INFORMATION

5.1 General

The preceding sections are concerned, both theoretically and experimentally, with principles. To help in applying the principles to actual investigations on the causes of prematures, some additional information from the laboratory work is made available below. This section will have served no purpose unless further work ensues, and it is hoped these brief notes may indicate opportunities.

On simple ignition alone, with integrity of the charge and its adhesion over the whole wall surface, a high pressure is created and transmitted at several mm/μs. Prima facie the results will be: relief by distortion, ejection of fuze (or plug, etc.), or tensile failure of the shell.

With cracked fillings and poor adhesion, ignition seems more likely to occur but prima facie it will lead to the same results:

(a) Transverse cracks roughly parallel to the base must close up as the shot-start compression travels through the filling.

/Many .....

Many modes of heating are possible. Any ignition will spread over the surface of the crack concerned. Even with virtually instantaneous ignition of a reasonable area, the pressure rise must be accompanied by corresponding displacements over the same area, with the results already mentioned but perhaps with less delay.

(b) Poor adhesion favours frictional heating, though not exclusively. Reaction will spread over the exposed surface and may penetrate the adhesion interface; cooling by the metal can be ignored. Compared to duplicated surface of a crack in the filling, a non-adhering boundary surface is less able to sustain convective losses. No factors are seen which raise the chances of direct detonation, and the results already stated are the most likely.

5.2 Lateral Propagation through a Laminar Space

A disc 10 mm thick, cut from 19 mm diameter steel rod, was bored axially 1.58 mm diameter then fastened to a base (with electrode, insulation, seal, as usual) and filled flush to the top surface with PETN, 30 mg including igniting layer.

This served as a donor component and by placing a second disc on top, the reaction-products were confined to the laminar region of the interface. The response of acceptor charges flush filled into drilled cavities in either disc at chosen radial off-set distances could thus be examined, with or without spacing the interface by foil shims. An electrode placed at the circumference, or at an intermediate drilling, enabled the flash-emergence to be timed.

(A) Acceptor charge PETN, 20 mg, in cavity 5 mm deep, 1.58 mm bore, at 6 mm centres from donor was ignited and fully consumed; the cavity was expanded. Interface was spaced about 0.2 mm.

(B) Acceptor charge HMX in above conditions lost top surface only.

(C) Repeating with the donor (PETN) increased to 2.38 mm diameter (65 mg) the HMX acceptor 1.58 mm diameter was fully consumed.

(D) A 60/40 HMX/TNT mixture (ground) as another acceptor in the same experiment lost its surface only.

(E) A 60/40 HMX/TNT mixture (ground) 2.38 mm diameter, at 4 mm centres from 2.38 mm PETN donor, was eroded about 1 mm deep.

(F) Similar acceptor at 6.3 mm centres was eroded about 0.5 mm deep. These acceptors were in the same disc as the donor and no spacer was used at the interface - simply steel on steel with charges filled flush to the surface.

/(G) .....

(G) A 90/10 HMX/TNT (ground), 68 mg in 3.18 mm cavity 5 mm long, at 4.5 mm centres from 2.38 diameter PETN donor, left only 5 mg unconsumed at bottom of the cavity.

5.3 Lateral Propagation at Cross-section Enlargement

(H) An acceptor of 90/10 HMX/TNT (ground), 180 mg in 6.3 mm diameter cavity 3.3 mm deep, was aligned over and directly in contact with 2.38 mm PETN donor. Acceptor charge completely consumed, and the 6.3 mm cavity in 19 mm diameter disc was expanded to 7.8 mm diameter at the mouth.

(J) An acceptor of PETN, 160 mg in 6.3 mm diameter, directly above and in contact with a miniature PETN donor (3 mg, approx. 1 mm dia.) was completely consumed.

(K) Precisely similar results were observed with guncotton as donor and receptor. In these two experiments the wide acceptor cavity was drilled in the same cylinder of steel as the donor channel - a narrow coaxial extension - and a brass disc, 400 mg was pressed on top of the acceptor. The vigour of reaction of the acceptor, forty times larger in cross-section than the donor indicates the spread of the reaction at the enlargement of bore is very rapid.

5.4 Detonation at Cross-section Enlargement

(L) The principle described at the end of section 3.5, and illustrated by Fig. 2, was extended to initiation of a 12.5 mm diameter acceptor by a 1.58 mm diameter donor, both being housed in the same steel cylinder 18 mm long and 19 mm diameter. After pressing the ignition layer and donor charge of PETN (15 mg total) with 0.2 mm brass disc on top, 3 mm of the donor bore remained empty. The aperture was covered with a 3 mm disc of the same brass and the acceptor charge, 240 mg PETN, about 2 mm thick, was pressed into position with a steel disc on top. On firing, the acceptor charge detonated; the cavity rim surrounding it was sheared away.

(M) Similar firings were made with the donor charge pressed in a 1.58 mm axial bore in a steel disc 19 mm diameter 10 mm thick, leaving a space as before. The acceptor charge (500 mg PETN) was housed in a cylindrical cup of 0.5 mm thick aluminium into which the donor disc fitted snugly. The assembly was fired under water in a large plastic bucket to verify the detonation by its effect on an aluminium plate in a miniature metal-forming operation.

(N) An acceptor charge of 500 mg RDX gave exactly similar results.

(O) When the donor charge of PETN was increased to fill the bore and eliminate the space, so that direct contact with the acceptor charge of PETN was made, the result on firing was altogether different. A hole

/about .....

about 9 mm diameter was torn in the centre of the aluminium cup, the metal being petalled back. About half the acceptor charge remained intact around the outer area of the cup. The thin layer of PETN, plus the water medium backing it, did not give enough impedance to ensure full detonation, and partial displacement resulted.

(P) An acceptor charge of 70/30 RDX/TNT mixed by grinding did not detonate. The cup was torn open, and of the 500 mg charge about 400 mg was recovered.

(Q) Acceptor charges of PETN/TNT, mixed by grinding, were made in the weight proportions 90/10, 80/20, 60/40, 50/50. All detonated successfully in contrast to the RDX/TNT above.

(R) However, a 50/50 composition which had been melted in the cup, and re-solidified before assembling, remained largely unconsumed but ejected from the cup which was bulged and torn open.

5.5 Crucial Effect of Impedance

Acceptor charges were pressed in 6.3 mm id steel sleeves about 12 mm long, 1.58 mm wall-thickness, to form a compact column at one end, leaving a space of <5 mm into which the donor fitted. The donor consisted of 6.3 mm od steel rod, 10 mm long, with axial bore containing the electrode, igniting layer, and donor charge of PETN. At the end which butted against the acceptor charge when assembled, the donor bore had 3-4 mm unfilled. Firing was carried out under water, using an aluminium plate supported on an evacuated die to register the shock qualitatively.

(S) An acceptor charge of PETN, 200 mg, 3.5 mm length, gave a low-order explosion; the containing sleeve expanded to a bell shape, 9 mm id at the mouth.

(T) A similar 200 mg charge of PETN, 3.5 mm length, was pressed on top of a layer of pressed lead oxide, 300 mg, 1.5 mm length, thereby providing greater inertia and impact-pressure. On firing, the acceptor this time detonated, shattering the sleeve into small jagged fragments. Resulting from the intense pressure, the donor sleeve was crushed about 1 mm shorter in length, with expansion of the diameter and bore.

(U) Conjoined donor and acceptor parts in a single piece of steel, with no empty space between the two parts of the charge, gave a low-order explosion of the PETN although supported on 300 mg of PbO as before. The sleeve was expanded in bore by less than 1 mm, contrasting with the first experiment of the three.

5.6 Mechanical Ignition

(V) Making use of an assembly similar to Fig. 1(b), ignition by forming hot-spots in presence of grit was easily achieved. The electrode wire

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was replaced by a hardened steel rod 1 mm diameter passing through a clearance hole in the end of the sleeve, with talc pressed at the inside to form a seal. The charge was either PETN, RDX, or HMX, with sand or crushed glass added to increase sensitiveness. A thin layer of talc and a brass disc were used to cover the charge at final pressing.

With the sleeve supported vertically and the rod uppermost, firing was accomplished by striking the rod with a falling weight, typically 56 g from a height of 35 cm. The kinetic energy in this case is 200 mJ. Other things being equal, the mechanically-produced thermal ignition should have just the same consequences as electrothermal ignition. This was confirmed by perforating witness plates when using charges shorter than the bore, as in section 3.5. These experiments also indicated that very little movement of the rod was needed to produce ignition by the grit particles in the firmly-consolidated charge. The striking velocity was less than 3 m/s.

6. PROSPECTIVE EXPLOITATION

It should be noted that laboratory limitations enforced the use of very small quantities in the work described, consequently it was easier to obtain results with pure rather than desensitised explosive. In particular, the inertia and the duration of stress-transmission of these small charges were low, and the use of water as enveloping medium was in some instances successful in these respects. With facilities for firing larger masses, however, it is probable that RDX/TNT would respond to some of the techniques described.

Electrothermal ignition by use of a few milligrammes of guncotton, PETN, or RDX offers a convenient basis for static (and conceivably for ballistic) experiments on the consequences of ignitions, without prejudice to the causes.

Use of partial fillings and simulated portions of rounds could allow stresses and movements to be examined and correlated with nature and location of ignition, with presence of cracks, faulty adhesion, etc.

It seems particularly desirable to assess the relevance or otherwise of pressures and stresses subsequent to ignition; i.e. in the first place to decide whether RDX/TNT can behave in the way PETN and RDX do, without necessarily choosing conditions resembling shell, etc., for this purpose. Sections 3.5, 5.4 relate to this.

Persistence and spreading of reaction from an ignition nucleus also needs to be examined, not only point to point as in Section 5.2 but over continuous surface as well. Comparison of a cast surface with a fractured surface would be of interest because of differences in exposure of RDX (compare for instance, Q and R).

/Finally .....

Finally on the basis of Section 3.5, pressure and acceleration conditions more severe than those in the gun can be simulated with relatively simple equipment. The conditions for ignition by gas-compression, grit particles, or impact of cracked surfaces could perhaps be explored by this means.

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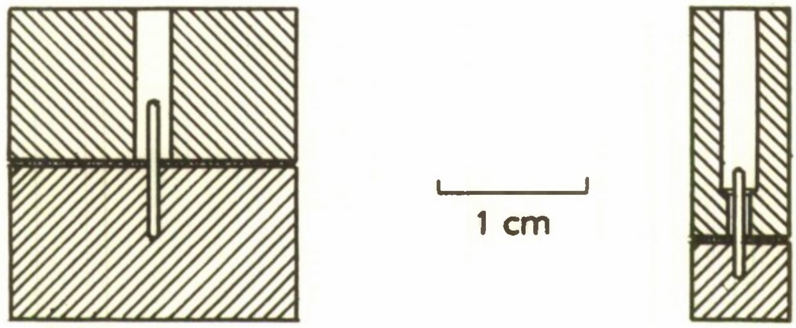
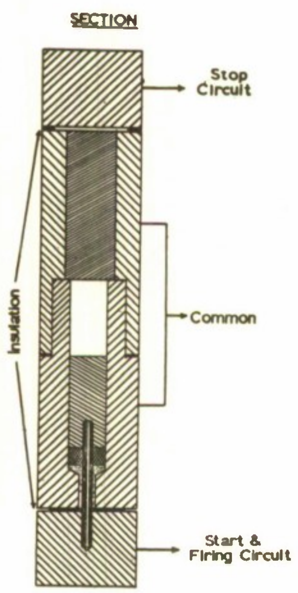
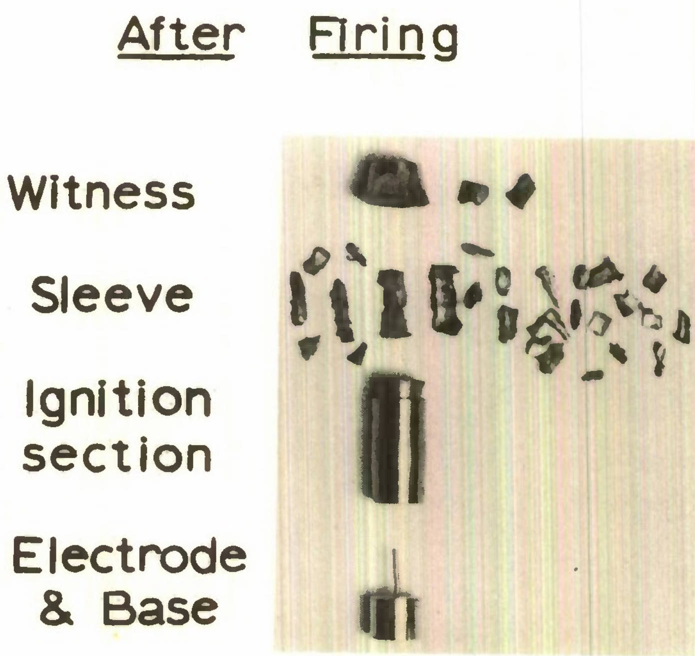


(a) (b)

FIG. 1.





(a) (b)

FIG. 2.

THESE INDEX CARDS ARE SUBJECT TO THE SAME SECURITY REGULATIONS AS THE PARENT REPORT AND THEIR LOCATION SHOULD BE RECORDED ON THE INSIDE OF THE BACK COVER

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Explosives Research and Development Establishment
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Lovecy, A.L.
August 1969
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